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Removal Efforts and Ecosystem Effects of Invasive Red Swamp Crayfish (*Procambarus clarkii*) in Topanga Creek, California

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Abstract.—Red swamp crayfish (*Procambarus clarkii)* were first recorded in Topanga Creek in 2001. When the onset of drought in Southern California resulted in low flows and warming water temperatures from 2011–2014, the population rapidly increased. Within the Santa Monica Mountains, *P. clarkii* has been linked to diminishing numbers of California newt (*Taricha torosa*), a species of special concern (Kats et al. 2013). To address these concerns, a student-based citizen science program was conducted from November 2013 through April 2014 to remove crayfish from a 200 m reach of Topanga Creek. The following data was collected and compared between the removal reach and an upstream, adjacent 200 meter non-removal reach (control): water quality (temperature, salinity, pH, conductivity, dissolved oxygen, turbidity), nutrient levels (nitrate, nitrite, ammonia, orthophosphate), benthic macroinvertebrate community metrics, crayfish demographics and catch-per unit effort (removal reach only). The results indicate that red swamp crayfish presence or removals do not affect water quality or nutrient levels in Topanga Creek. However, benthic macroinvertebrate communities were significantly different between reaches; the presence of crayfish correlated with lower BMI abundance and species richness, higher proportion of tolerant taxa, and lower feeding group complexity.

Red swamp crayfish (*Procambarus clarkii*) have spread far across the globe, posing an invasive threat to freshwater species abundance and community diversity (Ficetola et al. 2011). Mediterranean wetlands, such as those found along the southern coast of California, have been shown to be preferred habitat for *P. clarkii* in periods of drought with reduced flows and increased water temperatures (Geiger et al. 2005). This crustacean grows rapidly, maturing within three months after hatching, and can reproduce twice a year in warm conditions (Barnes 1974; Vodopich and Moore 1999). Large healthy females typically produce 600 viable young furthering their ability to spread quickly (Barnes 1974; Vodopich and Moore 1999). *Procambarus clarkii* are omnivorous consumers of an array of plant and animal matter such as macrophytes, detritus, amphibian eggs and larvae, aquatic invertebrates, and small fish, thus affecting the riparian food web on a polytrophic scale (Momot et al. 1978; Momot 1995; Stenroth and Nyström 2003). The generalist and predatory feeding habits of *P. clarkii* have been linked to observed declines in macrophyte abundance (Feminella and Resh 2006; Rodriguez et al. 2005), amphibian species richness and recruitment (Gamradt and Kats 2002; Cruz et al. 2006; Ficetola et al. 2011), and macroinvertebrate diversity (Correia and Anastácio 2008).

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Red swamp crayfish were detected in southern California as early as 1924 (Holmes 1924), but not observed in Topanga Creek until 2001 (*RCDSMM unpublished data*). Topanga Creek is the third largest coastal watershed (47 km^2) draining into the Santa Monica Bay. Freshwater systems in this region are critical habitat that support a number of sensitive and endangered native aquatic species. *Procambarus clarkii* were the first introduced fauna to become established and spread throughout Topanga Creek, and remains the most abundant non-native invasive in the watershed. The population of *P. clarkii* in Topanga Creek was initially suppressed by active removal efforts and significant winter rain events and sufficient flows to reduce crayfish abundance (Kats et al. 2013). Below average rainfall and low flows in 2011–2014 have facilitated the extensive establishment of *P. clarkii* throughout Topanga Creek.

The population growth of *P. clarkii* in Topanga Creek raised concerns about possible implications for two native species, the California newt (*Taricha torosa*), a California species of special concern, and federally endangered southern steelhead trout (*Oncorhynchus mykiss*). Data collected from Topanga Creek during snorkel and other visual surveys (2001–2014) documented the spread and increased abundance of *P. clarkii*, as well as provided direct observations of crayfish attacking newts (*RCDSMM unpublished data 2014*). The interactions of crayfish and *O. mykiss* are less clear; however, since 2011 an increased incidence of crayfish found in the diet of large (>25.4 cm) *O. mykiss* has been observed (Krug et al. 2012).

Benthic macroinvertebrates (BMI) are an important food source for both *P. clarkii* and *O. mykiss* (Angradi and Griffith 1990, Nystrom and Graneli 1996). Competition for food resources and disruption of BMI community functionality is a potential concern. The complexity of functional feeding groups (e.g., gatherers, filterers, scrapers, predators) can be a measure of the functional integrity of BMI communities and a reflection of its capacity to cycle nutrients (Wallace and Webster 1996). Disturbance to the benthic community, such as the introduction of non-native fauna, can alter BMI community composition and cause unanticipated changes in freshwater ecosystems (Covich et al. 1999). Changes in BMI abundance, diversity, and feeding group complexity can indicate such community disturbance.

In Topanga Creek, drought induced low flows in 2011–2014 resulted in isolated refugia pools and reduced numbers of *O. mykiss* redds and young of the year[1]. However, *P. clarkii* were able to successfully reproduce and inhabit the shallow riffles and fragmented reaches inaccessible to *O. mykiss*. In September 2013, the Resource Conservation District of the Santa Monica Mountains (RCDSMM), in conjunction with the Watershed Stewards Program (WSP), launched a citizen science program that 1) removed crayfish from several refugia step-pool habitats within a 200 meter reach of Topanga Creek, 2) measured crayfish demographics (sex/length), and 3) monitored water quality (dissolved oxygen, pH, salinity, conductivity, turbidity, water temperature), nutrient levels (nitrate, nitrite, ammonia, phosphate), and BMI community metrics.

Materials and Methods

Topanga Creek (34° 6’11”N 118° 36’18” W, gradient 1 to 6%) is the main drainage of a small coastal watershed (approximately 47 km^2) located within the Santa Monica

[1] Krug, J., R. Dagit, Stillwater Sciences, and J.C. Garza. 2014. Lifecycle monitoring of *Oncorhynchus mykiss* in Topanga Creek, California. Final Report Prepared for CA Department of Fish and Wildlife, Contract No. PO950013. January 2014.

Mountains National Recreation Area in southern California. The study reach consisted of 400 continuous meters in Topanga Creek, starting at 3500 m (upstream from the ocean) and ending at 3900 m. The study area included a downstream 200 m crayfish removal reach (RR), and an upper 200 m non-removal reach (NRR; Fig. 1). Both reaches were relatively uniform in geomorphological features, including a similar distribution of pools, step-pools, runs, and riffles, substrate type, and percent canopy cover. No introduced barriers of any sort were incorporated into the study reaches; however, natural low-flow boulder barriers separated the RR from the NRR.

A total of ten volunteer crayfish removal events took place between September 2013 and April 2014. Water quality, nutrient, and BMI samples were collected in both 200 m reaches during removal events between November 2013 and April 2014. Crayfish were removed throughout RR with 7.6 cm hot dog pieces attached to hemp strings. The presence of federally listed *O. mykiss* prevented setting traps of any kind. Crayfish were counted, sexed, and measured (cm) from the tip of the rostrum to the end of the tail in midline. Removed crayfish were donated to a local wildlife rescue or used for educational purposes.

Water samples were collected from three pools within each 200 m reach an hour prior to removal. Each site was tested for air temperature (mercury thermometer), salinity (ATC 300011 SPER SCIENTIFIC salt refractometer), pH (Oakton pHTestr 30), conductivity (Oakton ECTestr11), dissolved oxygen (DO) and water temperature (YSI 55 DO meter). All probes were calibrated within a week prior to the collection date. Nutrient and turbidity sampling was conducted once a month from November 2013 through April 2014 at 3500 m, 3550 m, and 3600 m in RR and at 3700 m, 3800 m, and 3850 m in NRR. Samples were tested for nitrate-N (ppm), nitrite-N (ppm), ammonia-N (ppm), orthophosphate (ppm) and turbidity (NTU) within eight hours of collection using LaMotte SMART3 colorimeter and LaMotte 2020we turbidity meter.

BMI samples were collected according to CA Rapid Bioassessment protocol[2] in November 2013, December 2013, February 2014, and April 2014 at three comparable sites in RR and NRR. Each sample was composed of nine kicks into a 1-ft. wide D-frame net (three transects and three kicks per transect). Samples were preserved in 95% ethanol and processed within a month from collection date. BMI were identified to genus, or lowest possible taxonomic level using a 40x magnification dissecting microscope. *P. clarkii* was recorded but not included as a benthic macroinvertebrate for analysis. For quality assurance, 10 percent of samples were randomly selected and re-identified by a second processor. First and second identifications were compared and scored for accuracy, resulting in an estimated error of 1.6%.

Paired t-tests were applied to determine any significant difference between the two reaches in crayfish demographics, water quality, nutrient levels, and biotic integrity metrics of BMI communities. Regression analyses were performed to compare water quality metrics to crayfish removal and to analyze the relationship between catch per unit effort and water temperature. Simpson's Index of Diversity (Simpson 1949) was calculated for each BMI sample and analyzed by paired t-test to compare biodiversity. Simpson's was also applied to samples categorized by functional feeding groups (gatherers/filterers, scrapers, predators, or other) to compare feeding group complexity. Southern Coastal California Index of Biotic Integrity (SCC-IBI; Ode et al. 2005) metrics

[2] Ode, P.R. 2003. CAMLnet: list of California macroinvertebrate taxa and standard taxonomic effort. Aquatic Bioassessment Laboratory, Rancho Cordova. Retrieved September 10, 2014 from http://www.safit.org/ste.html.

Fig. 1. Map of Topanga Creek Watershed and the crayfish study reaches (3500–3700 Removal Reach (RR); 3700–3900 Non-Removal Reach (NRR)).

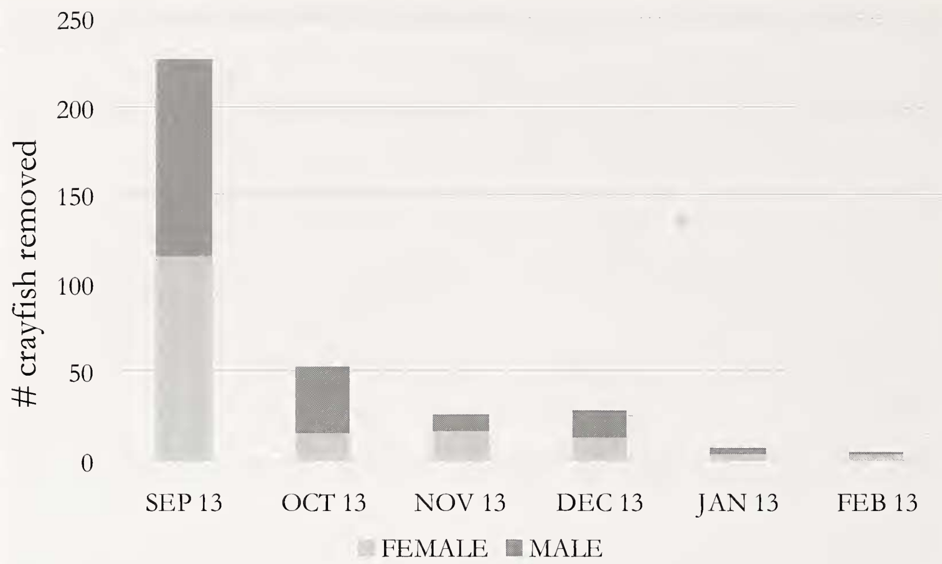

Fig. 2. Total number of male and female crayfish removed each month Oct. 2013 to Feb. 2014.

(number of EPT, Coleoptera and predator taxa, and percent tolerant, intolerant, non-insect, and collector-gatherers + collector-filterers) were applied and scored for all BMI samples.

Results

Ten volunteer removal events between September 2013 and April 2014 (203.25 person-hours) resulted in the removal of 345 *P. clarkii*; 166 females and 179 males (Fig. 2). The average length of crayfish removed was 7.61(±0.348 SE) cm. There was no significant difference between male and female average length or number removed. The first event (9/21/2013) resulted in the most captures with more than four times as many crayfish removed than any proceeding month. The catch per unit effort (CPUE) in the study period November 2013 to February 2014 ranged from 0.1 to 3.0 crayfish per person per hour, and increased significantly with warmer water temperatures (R^2=0.67, F=12.27, p<0.05). An increase of approximately 0.26 CPUE was calculated for every 1°C increase in temperature (Fig. 3). The comparison of water quality and nutrient concentrations between the RR and NRR showed no significant differences, except for salinity. Salinity showed a statistical difference between reaches (paired two-tailed, $t(3)=-4.65$, $p<0.02$). The NRR had higher salinity throughout the course of the study, although levels in both reaches ranged from 0–2 ppm.

The four BMI samples collected from the NRR in November 2013, December 2013, February 2014, and April 2014 contained a total of 645 individuals and 38 taxa. The samples collected from the RR contained a total of 3,642 individuals and 51 taxa. A total of four phyla were represented including Arthropoda, Annelida, Mollusca, and Nematoda. BMI abundance was significantly higher (paired two-tailed $t(3)=3.59$, $p<0.04$) in the RR (Fig.4). In both reaches, there was an increase in BMI abundance from November through April. The NRR had significantly lower richness (paired one-tailed $t(3)=2.74$, $p<0.04$). However, species diversity as measured by Simpson's Index of

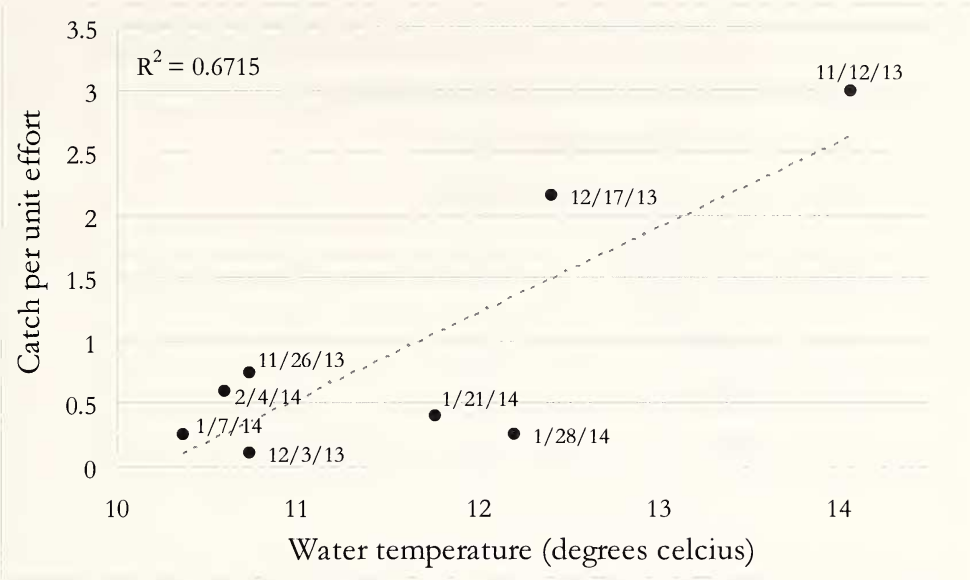

Fig. 3. Relationship between CPUE (catch/person/hour) and Water Temperature (°C) in Topanga Creek Nov. 2013 to Feb. 2014.

Diversity (Simpson 1949) was not significantly different between sites and ranged from 0.66 to 0.84 for all samples.

In the RR, the three most dominant taxa were Chironomidae (midge larvae, 24%), freshwater snails (Viviparidae and Hydrobiidae, 22% relative abundance), and *Hyalella* (freshwater Amphipod, 15%) (Fig. 5). The three most abundant taxa in the NRR were

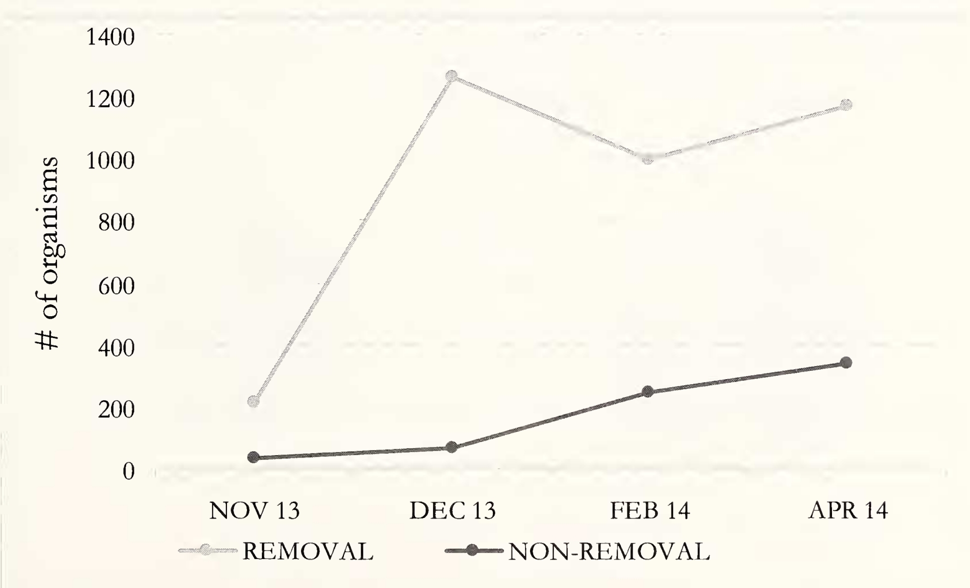

Fig. 4. Benthic macroinvertebrate abundance in samples collected from removal (RR) and non-removal (NRR) Nov. 2013 to Apr. 2014.

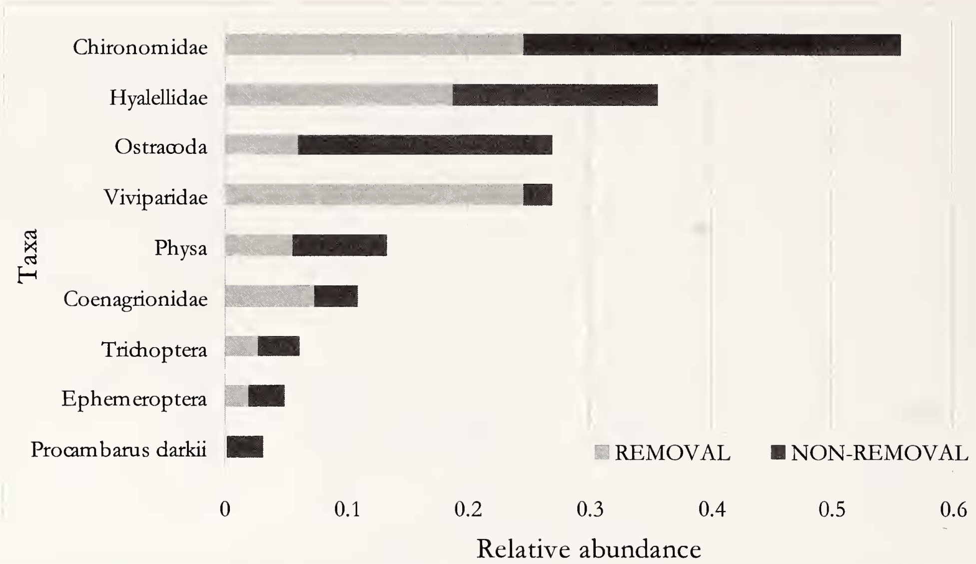

Fig. 5. Eight dominant taxa collected in each 200m study reach.

Chironomidae larva (33%), Ostracoda (seed shrimp, 22%), and *Hyalella* (18%). The two reaches shared the same six most dominant species, including the above mentioned with the addition of Coenagrionidae (narrow-winged damselfly nymphs) and *Physa* (physa snails). These dominant taxa described above each have a tolerance value of 8, with the exception of Chironomidae, which has an assigned tolerance value of 6 although there is great variation among genera and species.

While total SCC-IBI scores showed no trend, two SCC-IBI metrics differed significantly between sites: % tolerant taxa and % collector-gatherer + collector-filterer. The NRR had greater % tolerant taxa (tolerance values 8-10) than RR (paired two-tail $t(3) = -5.24$, $p = < 0.02$). The NRR had a greater proportion of collector-gatherer and collector–filterer organisms (paired two-tail $t(3) = -3.70$, $p < 0.04$) and fewer scraper organisms (paired two-tail

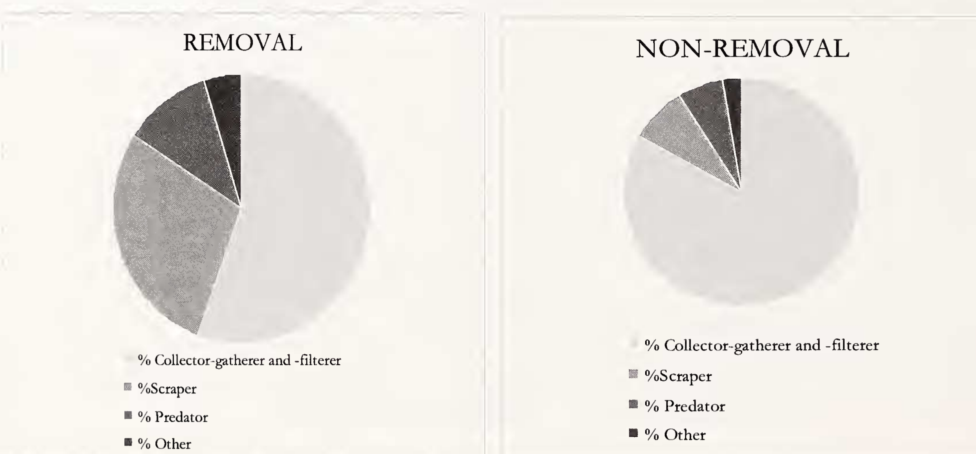

Fig. 6. Average functional feeding group composition in removal and non-removal reach samples Nov. 2013 to Apr. 2014.

$t(3)=4.05$, $p<0.03$). In applying Simpson's Index to sample data categorized by functional feeding groups, functional feeding group diversity was significantly higher in the RR (two-tailed, $t(3)=3.41$, $p<0.05$) (Fig. 6). Additionally, *P. clarkii* were collected more often in NRR BMI samples (3.1%, 20 individuals total) than in RR (<1%, 7 ind.).

Discussion

The invasive *Procambarus clarkii* has been shown to have severe effects on native aquatic wildlife in southern California streams (Riley et al. 2000, Gamradt and Kats 2002, Rodriguez et al. 2005, Cruz et al. 2006, Feminella and Resh 2006, Correia and Anastácio 2008, Ficetola et al. 2011). In Topanga Creek, benthic macroinvertebrate abundance and species richness were significantly higher in the 200m RR where crayfish were actively managed by hand-removal than in an adjacent NRR. This result is consistent with previous reports that correlate non-native crayfish presence to reduced BMI abundance in freshwater systems (Charlebois and Lamberti 1996, Stewart et al. 1998). In the RR, BMI samples contained between 23 and 51 distinct taxa and in the NRR, richness ranged from 6-38. This finding corroborates previous studies that have found that *P. clarkii* invasions lead to loss of BMI diversity (Rodriguez et al. 2005, Correia and Anastácio 2008). Functional feeding group diversity was lower in the NRR, and % of tolerant organisms was higher.

Increased abundance of BMI in RR indicates higher productivity for a number of taxa. Six distinct taxa had more than 100 individuals in one or more samples from the RR including Viviparidae and Hydrobiidae, Chironomidae, Hyalellidae, Coenagrionidae, Ostracoda, and *Physa*. Only two taxa had more than 100 individuals in any one NRR sample: Chironomidae and Ostracoda. A major distinction between community was that Viviparidae and Hydrobiidae were most abundant taxa in RR, but relatively rare in NRR (3%). The relative rarity of freshwater snails (scrapers) in the NRR diminished feeding group complexity. *Procambarus clarkii* predation on Viviparidae in this reach is one possible driver of reduced abundance of the genus, although micro-habitat differences within the 400 m study reach are another potential factor. Higher abundance, species richness, feeding group complexity, and a smaller proportion of tolerant species indicate that the BMI community in RR was in better ecological condition than in NRR. As crayfish are generally the largest species within the BMI community, a comparison of BMI sample proportional dry weight of taxa groups would further our understanding of *P. clarkia* effects on trophic-level productivity by providing a quantitative measure of biomass.

The ecological implications of invasive *P. clarkii* in Topanga Creek could be severe if they significantly disrupt benthic macroinvertebrate communities. BMI make up the primary consumer trophic level and play an integral part in nutrient decomposition and cycling through riparian systems. Changes at this level could impact higher trophic organisms such as California newts (species of special concern) and southern California steelhead trout (endangered). How the continuation of drought conditions within the region will continue to affect the population and impact of *P. clarkii* is uncertain; reduced flows and higher temperatures place stress upon aquatic natives, it renders riparian habitat more preferential for crayfish.

Water quality and nutrient results between reaches were less notable. Salinity was the only parameter to differ significantly, which may be influenced by a groundwater seep in NRR at 3900 m[3]. Some studies have suggested *P. clarkii* may be a source of bioturbation

[3] GeoPentech. 2006. Hydrogeologic Study Lower Topanga Creek Watershed, Los Angeles County, CA. Prepared for the RCD of the Santa Monica Mountains. Topanga, CA.

(Mueller 2007, Yamamoto 2010), however, results in this study showed no significant difference in turbidity between the RR and the NRR.

The level of effort per crayfish removed increased over the course of the study at a rate that correlated to decreasing water temperatures. While decreased activity is one possible factor, diminished crayfish numbers due to removal efforts is another. Removal events might be most efficient in warmer months; however a more extensive study including more removal areas and a longer time period is needed to determine whether there is a relationship between temperature and catch per unit effort, as well as to more completely characterize the effects of crayfish on water quality and the benthic macroinvertebrate community in Topanga Creek.

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Literature Cited

Angradi, T.R. and J.S. Griffith. 1990. Diel Feeding Chronology and Diet Selection of Rainbow Trout (*Oncorhynchus mykiss*) in the Henry's Fork of the Snake River, Idaho. Canadian Journal of Fisheries and Aquatic Sciences, 47:199–209.

Barnes, R. 1974. Invertebrate Zoology. Philadelphia, PA: W.B. Saunders Company.

Charlebois, P.M. and G.A. Lamberti. 1996. Invading Crayfish in a Michigan Stream: Direct and Indirect Effects on Periphyton and Macroinvertebrates. Journal of the North American Benthological Society, 15(4):551–563.

Correia, A. and P. Anastácio. 2008. Shifts in aquatic macroinvertebrate biodiversity associated with the presence and size of an alien crayfish. Ecological Research, 23(4):729.

Covich, A.P., M.A. Palmer, and T.A. Crowl. 1999. The Role of Benthic Invertebrate Species in Freshwater Ecosystems. BioScience, 49:119–127.

Cruz, M., R. Rebelo, and E. Crespo. 2006. Effects of an introduced crayfish, *Procambarus clarkii,* on the distribution of south-western Iberian amphibians in their breeding habitats. Ecography, 29(3): 329–338.

Feminella, J. and V. Resh. 2006. Submersed macrophytes and grazing crayfish: an experimental study of herbivory in a California freshwater marsh. Ecography, 12(1):1–8.

Ficetola, F.G., M.E. Siesa, R. Manenti, L. Bottoni, F. De Bernardi, and E. Padoa-Schioppa. 2011. Early assessment of the impact of alien species: differential consequences of an invasive crayfish on adult and larval amphibians. Diversity and Distributions, 17(6):1141–1151.

Gamradt, S. and L. Kats. 2002. Effect of Introduced Crayfish and Mosquitofish on California Newts. Conservation Biology, 10(4):1155–1162.

Geiger, W., P. Alcorlo, A. Baltanás, and C. Montes. 2005. Impact of an introduced Crustacean on the trophic webs of Mediterranean wetlands. Biological Invasions, 7(1):49–73.

Holmes, S. 1924. The genus *Cambarus* in California. Science, 60(1555):358–359.

Kats, L., G. Bucciarelli, T. Vandergon, R. Honeycutt, E. Mattiasen, A. Sanders, S. Riley, J. Kerby, and R. Fisher. 2013. Effects of natural flooding and manual trapping on the facilitation of invasive crayfish-native amphibian coexistence in a semi-arid perennial stream. Journal of Arid Environments, 98:109–112.

Krug, J., E. Bell, and R. Dagit. 2012. Growing up fast: diet and growth of a population of *Oncorhynchus mykiss* in Topanga Creek, California. California Fish and Game Bulletin, 98(1):38–46.

Momot, W.T. 1995. Redefining the Role of Crayfish in Aquatic Ecosystems. Reviews in Fisheries Science, 3:33–63.

———, H. Gowing, and P.D. Jones. 1978. The dynamics of crayfish and their role in ecosystems. American Midland Naturalist, 99:10–35.

Mueller, K.W. 2007. Reproductive habits of non-native red swamp crayfish (*Procambarus clarkii*) at Pine Lake, Sammamish, Washington. Northwest Science, 81(3):246–250.

Nystrom, C.B. and W. Graneli. 1996. Patterns in benthic food webs: a role for omnivorous crayfish? Freshwater Biology, 36(3):631–646.

Ode, P.R., A.C. Rehn, and J.T. May. 2005. A quantitative tool for assessing the integrity of southern California coastal streams. Environmental Management, 35(4):493–504.

Riley, S.P.D., G.T. Busteed, L.B. Kats, T.L. Vandergon, L.F.S. Lee, R.G. Dagit, J.L. Kerby, R.N. Fisher, and R.M. Sauvajot. 2005. Effects of urbanization on the distribution and abundance of amphibians and invasive species in southern California. Conservation Biology, 19:1894–1907.

Rodriguez, C.F., E. Becares, M. Fernández-Aláez, and C. Fernández-Aláez. 2005. Loss of diversity and degradation of wetlands as a result of introducing exotic crayfish. Bioinvasion Science, 7:75–85.

Simpson, E.H. 1949. Measurement of diversity. Nature, 163:688.

Stewart, T.W., J.G. Miner, and R.L. Lowe. 1998. An experimental analysis of crayfish (*Orconectes rusticus*) effects on a *Dreissena*-dominated benthic macroinvertebrate community in western Lake Erie. Canadian Journal of Fisheries and Aquatic Sciences, 55:1043–1050.

Stenroth, P. and P. Nyström. 2003. Exotic crayfish in a brown water stream: Effects on juvenile trout, invertebrates and algae. Freshwater Biology, 48(3):466–475.

Vodopich, D. and R. Moore. 1999. Biology Laboratory Manual. The McGraw Hill Companies Inc. USA.

Wallace, J.B. and J.R. Webster. 1996. The Role of Macroinvertebrates in Stream Ecosystem Function. Annual Review of Entomology, 41:115–139.

Yamamoto, Y. 2010. Contribution of bioturbation by the red swamp crayfish *Procambarus clarkii* to the recruitment of bloom-forming cyanobacteria from sediment. Journal of Limnology, 69(1):102.